An Enterprise Architecture based on Cloud, Fog and Edge Computing for an Airfield Lighting Management System

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***Abstract*—Followed by the introduction of IoT and new sustainable technologies, energy management, Quality of Service and decrease of communication costs become important and complex for enterprise systems at airports. The aviation authorities' reports reveal that the airport ICT investments are mainly focused on travel safety, mobile commerce, and new technologies. The main idea behind a smart airport is to deploy IoT network managed through a Cloud-Fog-Edge paradigm for a smart platform and optimize the airport's efficiency. An IoT cloud-based platform solution supports multiple types of data, advanced analytics, artificial intelligence, and machine learning techniques. However, cloud computing has certain limitations such as increased delay in data reporting, increased latency in accessing user network, limited customization, increased reliance on external network and data privacy. Fog-Cloud and Edge-Cloud paradigms can overcome the weaknesses of cloud computing architectures. Therefore, to understand the organizational impact of combining the usage of cloud, fog, and edge computing, we created an enterprise architecture that can be applied in a smart airport demonstration study. The enterprise architecture modelling was done by using ArchiMate and validated by means of an expert assessment and prototype implementation.**

***Keywords*-enterprise architecture, smart airport solutions, cloud computing, fog computing, edge computing**

I. Introduction

Information Technology (IT) is becoming more pervasive and at the same time it is modifying the way information is exchanged and is extending its possibilities [1]. It is not only about the IT itself, but also regarding all domains that are interacting with it. The increased storage, bandwidth, and fast computation support appearance of new services, which allow new business models to enable competition and create innovation possibilities. One paradigm that supports the implementation of these business models with the help of IT is EA. The enterprise architecture (EA) paradigm is playing an important role in the current corporate management. The EA as a paradigm is about defining enterprise components across different domains and enabling interactive communication between them. There are several frameworks which support composing enterprise architectures: Generalized Enterprise Reference Architecture and Framework (GERAM) [2], The Open Group Architecture Framework [3], Architecture for information system (ARIS) [4], and Zachman [5]. Current EAs expand the domains into three layers such as: business, application, and technology layer.

One of the promising application domains of EA we will focus on, is smart airport solutions. Smart IoT devices (LED lights) equipped with sensing and actuation capabilities are installed on the runway area, to monitor certain parameters such as temperature, light condition, and pressure changes. Fuel consumption rates or airplanes costs can be high when there is a failure of one sensor-based light installed on the runway, which is commonly used to support visual navigation for airplane's landing phase. In such circumstances, the airplane is not allowed to land and is forced to circulate in air, which contributes to higher fuel consumption costs, and air and environment pollution. Data are typically gathered in the cloud, where they could be processed, and by using machine learning techniques, failures can be predicted and then appropriate actions can be taken to deal with the new alterations.

The cloud has noticeable advantages, however when considering huge amounts of data and large networks, a cloud computing solution for airports deals with certain limitations. Additionally, the cloud computing servers are typically deployed in physical locations that are far away from the Internet Of Things (IoT) devices [6]. These limitations cause large delays in data reporting and increase in latency in the application of corrective actions. The National Institute of Standards and Technology (NIST) defines cloud computing as a model that allows the sharing of many computing resources as services to various clients. In this model, users can easily change or adjust their service requirements at a low cost [7].

In order to overcome some of the limitations that the cloud computing is struggling with, the concept of fog computing has been introduced. Fog computing was first proposed in CIES III Congress, January 2012 [8] and was further introduced by Cisco in 2014. In fog computing the data processing tasks are offloaded on to the numerous middle-ware devices present in the network as a middle layer between the cloud and the edges. This way the time taken for the data to be transferred over to a cloud environment is eliminated and it results in lower latency.

In addition to this, another computing paradigm called edge

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computing emerged where the data processing is offloaded on the edge device itself [9]. Due to data transferring with limited network performance, centralized cloud computing structure is becoming inefficient for processing and analysing huge amounts of data collected from IoT devices. Edge computing offloads computing tasks from a centralized cloud to the edge near the IoT devices, and the transferred data are reduced by the pre-processing procedures [9]. There are several research studies that successfully integrated the emerging fog and mobile edge computing paradigms in an IoT context, resulting in reducing response times and energy consumption e.g. [9], [10], [11], [12].

Being motivated to overcome these specific limitations and inspired by some of the studies above, we have designed an innovative solution that will lead to emergence of a Cloud-Fog-Edge architectural paradigm applied in a smart airport demonstration. This emerging architectural concept will bring the IoT access network and cloud closer to each-other and will support real-time applications. In this paper, we focus on developing an application and technology layer that will align to the business processes defined in the business layer of a smart airfield lighting system architecture. The goal of the architecture is to show how the fog, cloud, and edge computing concept can be applied in a smart airfield lighting system demonstration.

The structure of the paper is organized as follows. Section II introduces the methodology used in this research study and Section III describes the related work done for enterprise architecture, smart airport solutions and the Fog-Edge paradigm. Section IV introduces our demonstration about airfield lighting management system (ALMS). Section V represents a novel architecture for Cloud-Fog-Edge computing in an airfield lighting system, whereas its validation is elaborated in section VI. Section VII draws the delivered contributions of this research study. Finally, section VIII concludes this paper and recommends further improvements that can be used as a follow-up of this article.

II. Methodology

This research study is directed according to the principles of Design Science Research Methodology (DSRM) focused on development of artefacts in order to solve real-world problems, which is proposed by Hevner [13]. The outcome of a design-science research in IS is a purposeful artefact created to address a specific organizational problem. It needs to be effectively described, to enable a proper implementation, and to provide application in an appropriate domain [13]. According to the DSRM, there is a set of research activities for creating ALMS EA by completing analysis, design, development, evaluation, reflection, and abstraction activities, referred to in Figure 1. Furthermore, a prototype is developed as a method to address the functionality of the considered architecture, and evaluation based on experts' opinion.

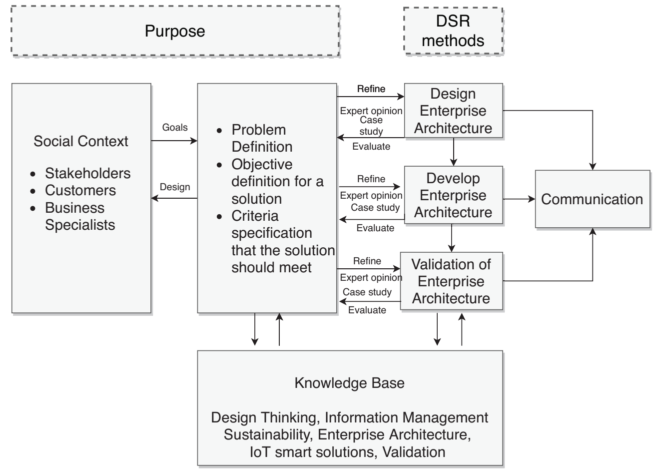

Fig. 1. Research Method

III. Background and Related Work

A. EA Modelling and Validation

The modelling language for EA is ArchiMate, which is the tool and the modelling environment of the suggested EA for ALMS [14]. One of the advantages of ArchiMate is that it provides a visual representation and encourages usage of different colours to highlight the different modelling layers. ArchiMate is an EA architecture modelling language which is based on TOGAF framework, one of the popular and accepted frameworks for enterprise architecture [14]. The mentioned three core layers: -business, -application, and technology - can belong to a full framework that can be extended by additional layers (physical, strategy and migration).

Additionally, the enterprise architecture methods can be used for providing organizational structure, business processes and the IT infrastructure of an enterprise. These methods can be applied to an IoT context in different domains, where we are interested in modelling the case studies, business objectives, processes, requirements, IT components, and data pipelines. ArchiMate language has been proven to be particularly helpful for modelling organizations which contain complex IT infrastructures [15].

In order to test and provide evaluation of the proposed architecture, in [16], the authors manifested the Situation-aware Smart Logistics EA by means of a prototype to support the scenario of transportation of perishable goods. They prototyped the business processes, the architecture, and provided implementation. The prototype implementation consists of implementing all modules specified in the SSLEA, including each test unit for each module [16]. The provided prototype was not meant for a production use, but only to represent a functional version of the SSLEA. It offered a user interface that supports essential functionality, which was needed for the demonstration. The first validation goal in their research study was managed by developing a scenario (case study), which was a representation for the user requirements, then they asked the stakeholders and experts to perform the defined scenario in order to get their opinion about how they experienced the specific system [16]. Their second validation goal (i.e., measuring performance) was linked to the functions of the primary system: to enable logistics exception handling faster and to ensure that the customer is aware that something can happen soon. Since these functions were highly correlated, in their case, this was corresponding in order to measure the throughput time from event occurrence to customer notification.

B. Taxonomy of Cloud-Fog-Edge Computing

This section elaborates more details regarding the taxonomy of a Cloud-Fog-Edge computing system. Cloud computing is that type of a paradigm that enables a on-request connection to a lake of resources. However, as already mentioned above, the number of devices is increasing, and therefore cloud computing is dealing with a lot of limitations in terms of privacy, security, and latency. In the given architecture in Figure 2 [17], the cloud is used to connect the manufacturers and the clients. The physical manufacturing system can be accessed to the cloud thankfully to the IoT (sensors, RFID tags, etc.). By using cloud-based solutions, the manufacturing enterprises can contribute to more efficient processes at significant lower costs. The fog represents a network group which is composed of connected fog nodes. The components of a fog network are: fog gateway and fog management nodes, and inner nodes [17]. The main role of a fog gateway is to enable the edge network access, receive data and handle data processing. The fog management node is controlling and having an overview of all fog nodes in the network. The inner fog nodes can communicate with the edge layer via the gateway, but its main function is to handle data processing on the data incoming from the edge layer. Then the inner fog can either process the data locally or send the data to other fogs.

The computation or processing in the edge computing layer happens at the edge part of the network, very close to the initial sources. Additionally, edge computing provides services which are close to its sources, in order to meet sensitive requirements regarding optimization, real-time services, and security [17]. The Cloud-Fog-Edge computing paradigm is presented in Figure 2, and this concept resembles the bridge between cloud and edge computing layer, which can be also applied in smart manufacturing applications. According to Figure 2, the edge layer consists of edge connectivity devices, smart robots, and terminals, which can also have the capability to analyse and process the generated data.

C. Smart Airport Solutions and Fog-Edge Computing Paradigm

According to [18], energy management has been crucial and at the same time complex for airports. It is known that the aviation industry is one of the biggest factors for air pollution and global warming. In this study, an integrated approach is suggesting to be adopted for Energy Management Information System (EMIS) in airports and the notion of sustainability is claimed through usage of EA based EMIS. The major

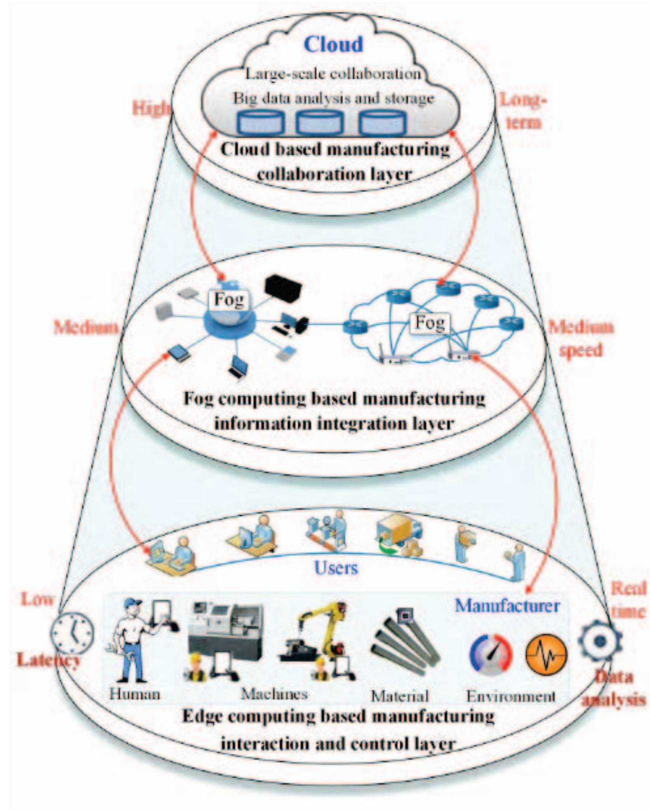

Fig. 2. Cloud-Fog-Edge Computing Overview for Smart Manufacturing [17]

contributions of this research are that, firstly it presents the first EA proposed for EMIS, specifically for airports. Secondly, it improves the evaluation and extensibility of EAs for EMIS. Thirdly, it provides establishment of consistency, dependency, and coherence to specifications of EAs through methods, tools, and ontological analysis. This study presents the importance of the sustainability idea through the use of EA-based and ontology-based EMISs. Additionally, it proposes ontology-based evaluation techniques for addressing existing main issues in EAs, such as, consistency, dependency, integration and interoperability.

This research study is also inspired by [19], where analysis solutions, data applications and services developed by the International Civil Aviation Organization (ICAO), such as indicators iSTARS, SIMS and iIMPLEMENT are presented. The solutions involve data-driven decision making and assist stakeholders in managing safety risks in support of development of safety information and implementation of state safety programs (SSPs) and safety management systems (SMSs). The transition towards a more predictive and systematic approach for safety management in aviation can be supported by data-driven decision making (D3M). The global air transportation systems are continuously growing and there is a proper need of analysis and data management which is considered as crucial successful safety performance. Only when the decision-making processes are based on the right data and information, then it is referred to as data-driven decision making. This component is implemented in the EA that we created for ALMS and it is very essential for the predictive maintenance entity which is a part of the application layer. Usually the data-driven decision making refers to making decisions that are based on relevant data and quantifiable evidences rather than on specific observations [19]. The purpose of D3M is to identify risks and opportunities, reduce human errors, determine a best-fit solution and deliver results to management and stakeholders in order to make effective decisions.

In [20], a Smart Fog Service is introduced in a context for an airport, with a main goal to represent its potential values that can be developed in environments with great presence of smart objects. Often fog computing is defined as a horizontal-level system architecture that involves more computing, control, storage, and networking functions being closer to the end-users than the cloud computing to the IoT objects. The deployments are expected to occur on multiple layers, while at the same time retaining certain benefits from cloud computing and that is containerization, orchestration. virtualization and efficient resource management. The processes are moved from the cloud to the elements near the edge network and those are the fog nodes which are dealing with autonomous processing, storage and network communications. The experimental Use Case on Smart Fog Hub Service (SFHS) has been described, by exposing the main objectives of exploring and analysing marketing and new revenue models through data collection and advanced analytics, and foreseeing new business models. It was distinguished that the data processing should be distributed between cloud and fog layers because the amount of data to be managed shall exceed network, storage, and computing capabilities at the fog layer. In the reviewed literature, we did not identify a research article considering an enterprise architecture based on Cloud-Fog-Edge paradigm used for an airfield lighting management system.

IV. Demonstration

In this section, we'll introduce a general description about smart solutions for an airport, which followed by our reference architecture for fog, cloud, and edge computing that can be used in ALMS. The proposed architecture should improve processing, decrease latency in communication, increase reliability of the system, optimize usage of resources, and improve resource management.

The ALMS involves the lights which are installed on airport taxiways, runways, and other specific areas. The sensor-based lights provide information on locations and directions for aircraft pilots, aircraft mechanics, maintenance workers, and Federal Aviation Administration (FAA) control-tower personnel. That is essentially helpful in situations with reduced visibility to perform operations with high safety. Airports also provide navigation lighting systems that are maintained and operated by FAA regulations [21]. These can include lighting systems and beacon lights that help the aircraft movements. For example, daylight conditions often require additional lighting for aircraft taxi, landing operations, and take-off. Additional lighting is also needed for airplane operations during specific hours of reduced visibility and during conditions which reduce the visibility at an airport. Usually, these conditions appear due to frequent changes of weather e.g., fog, rain, smog, and snow.

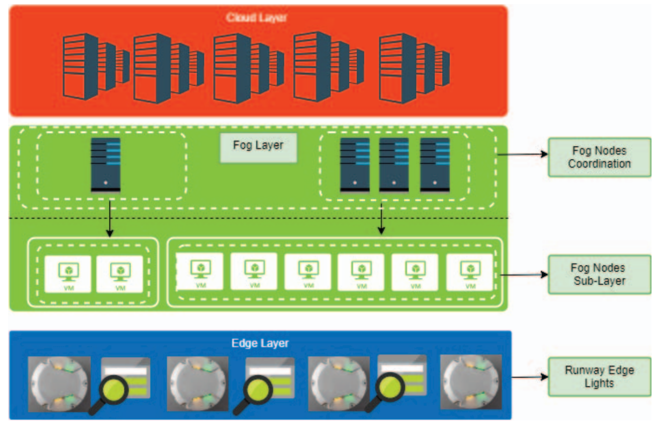

Fig. 3. Cloud-Fog-Edge Computing Overview

An ALMS facility enables visual guidance for an aircraft to land. The airfield runway will also provide vertical visual guidance while an airplane is approaching to land. That can be enabled by a directional pattern that should be followed to inform the pilots that they are on the right path. At the moment when an aircraft is approaching the runway and arrives on the landing area, the sensor lights will be activated and should light until the end of the runway. During visual navigation, the pilot will align the aircraft based on the light provided in the runway while approaching for landing, besides the instructions from the control tower. The airfield lighting system (ALS) is an important safety feature, which is necessary at every point for the implementation of night flying. Additionally, there is also a taxiway lighting that will provide a clear view and enable airplanes to reach the taxi platform [22]. The ALS incorporates connectors, lights, cabling, computer hardware, software, and sensors. There can be a few hundred to a few thousand lights depending on the size of the airport and the length of the runways and taxiways. The lights are controlled by a computer system which adjusts the lighting levels based on operational requirements, detected weather, and visibility conditions. The ALS also includes electrical systems controlled by control and monitoring computer software. Existing software applications differ by vendor and can conduct the function of controlling light levels on the airport's airfield differently. The majority of the software applications come up with a GUI that supports touch-control operations of the system. This type of software systems also has the functionality to send notifications to users when the conditions are changed within the system. However, these specific software applications can also be integrated with the airport's maintenance reporting system to automate service maintenance requests. An EA model can be used to represent services and operations that occur at airports.

V. Enterprise Architecture for ALMS

Figure 8 shows the proposed overall system, using the ArchiMate 3.0 language guidelines [23]. An ALSM is presented as a system abstract designed to create an international smart system development and implementation environment. It should give the reader a direction to physical interfaces, system components and data connections. As stated above, the main goal of this research is to propose an EA for a smart ALMS. The research study presented in [17], gave an overview of a taxonomy for Cloud-Fog-Edge paradigm which was used as an idea to use cloud, fog and edge computing layers and their components in the technology layer. Based on discussions with enterprise architecture experts, as well as a brief literature study, we proposed the architectural components as described below. With the help of an open interview done with a representative from an airfield company, we gathered information about the processes, applications and technology. Two enterprise architecture experts provided feedback to improve the quality of the model.

A. Business Architecture

The business architecture in our model focuses on the users, roles, and business processes. In theory, the business architecture defines business strategy, management, organization, and key business processes.

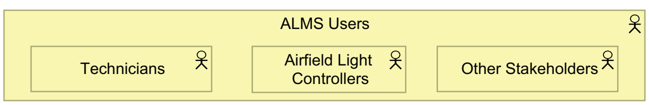

Fig. 4. Users

Figures 4 and 5 represent the business layer of our proposed EA, which refers to the users/roles and the business processes that can be completed by using the ALMS. Some of the ALMS users are: technicians, airfield light controllers and other stakeholders such as project leaders and managers. The services provided by ALMS are mostly related to the reliability and safety function of ALMS. There is a decision management business process, composed of data analysis, and optimization processes, which aggregate the monitoring business functions. The monitoring functions are: user behaviour monitoring, controlling airfield lighting area, and environment monitoring. The decision management business process realizes the ALMS services, which are data collection, data storage, business intelligence, and a dashboard report. Furthermore, as a part of the business layer is the ALMS Maintenance service, containing a Real-time Alert Generation function (containing notifications) is retrieved from the ALMS Services from the application layer and are realized in the business ALMS services.

B. Application Architecture

The application architecture represents a blueprint for personal application systems to be configured. Beginning by their interaction, they can relate to the core business processes of the organization.

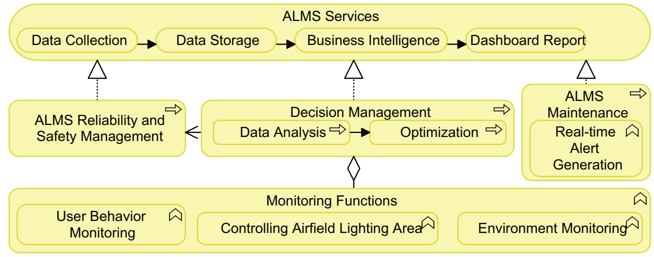

Fig. 5. Processes

The application layer as shown in Figure 6 comprises multiple components. The ALMS Maintenance application component and Embedded Software Control (used to control light intensity level) are aggregated into an application collaboration component, which is named as Maintenance Management and Predictive Maintenance. The generated information and alerts directly flow into the ALMS services. Data API from an Airport ERP system is composed of data, which is fed from the ALMS Maintenance component. The Maintenance Management and Predictive Maintenance application collaboration realizes the Data Processing application process which can access (read/write) the data object Database Records. The database records consist of several types of data: IoT Data, Weather APIs data, and other data sources.

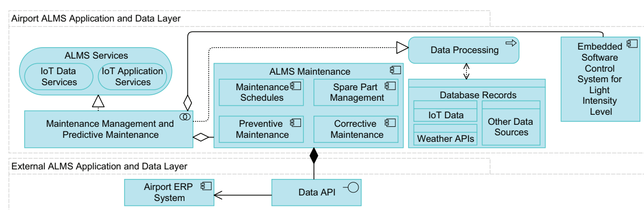

Fig. 6. Application Layer

C. Technology Architecture

The technology architecture describes the software and hardware infrastructure that provides support for core deployment and critical task applications. The technology architecture of ALMS EA (Figure 7) is mainly composed of three layers: cloud, fog, and edge. The ALMS Cloud Services technology component supports processing for large amount of data and storage. Additionally, the ALMS Cloud Services is related to a Message Broker. The Message Broker is important since it is used to manage communications between systems and cloud components in hybrid cloud environments. It ensures that data is sent securely and efficiently between application components. The message switching functions is done via the MQTT protocol. The MQTT protocol is a protocol for IoT and it is the preferred protocol for connecting devices to the cloud. It uses publisher/subscriber pattern to connect parties with each-other.

The fog layer component is positioned between the cloud and the edge layer. The fog layer consists of a Fog Node

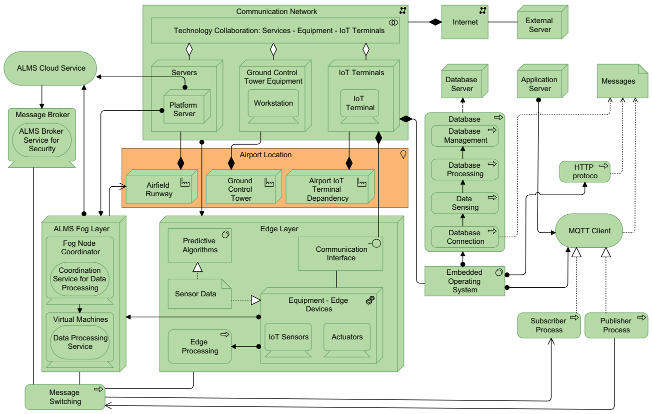

Fig. 7. Technology Layer

Coordinator and a Fog Node Sub-layer, which is composed of virtual machines. The Fog Node Coordinator provides a coordination service for data processing, while the virtual machines enable data processing services. Once the collected data from the edge layer is transmitted to the fog layer, the fog nodes take complete control over the data processing. The moment the fog nodes are overloaded with data, then the cloud takes control over certain amount of data processing and storage.

The edge layer consists of a communication interface, equipment of edge devices (sensors and actuators), edge processing, sensor data and predictive algorithms. Once data are collected via the IoT sensors and actuators, data can be also processed within the sensors themselves. The predictive algorithms are used to send notifications/alerts to the ALMS Maintenance System application component and support the decision management processes via the application collaboration Maintenance Management and Predictive Maintenance. The collected data can be also sent to the fog layer since it is nearly located to the edge devices, in order to enable fast data processing (improve latency). In other words, it causes reduction of the communication costs. The Servers, Ground Control Tower Equipment and IoT terminals as technology nodes are aggregated into a technology collaboration component and belong to a communication network node, which is linked to the cloud, fog, and edge layer as well. Additionally, the IoT Terminal is composed of a system software node-Embedded Operating System, which is assigned to support the Database technology processes: Database Connection, Data Sensing, Data Processing, and Database Management. Next, the information flows from the Database processes into the Database Server node.

VI. Validation of the Enterprise Architecture

A. Prototype

To validate the proposed EA for ALMS, we have developed a prototype that introduces some functionalities to its users, which was inspired by [16]. The goal of the prototype is to support the scenario of efficient alert generation to optimize the maintenance service for ALMS. The prototype does not cover all the aspects that are modelled in the architecture, but only the maintenance component which is presented in the application layer. The prototype was developed by using a ready software tool WebFlow [24].

1) Prototype Business Process: Figure 9 represents the process of alert generation to optimize the maintenance service for ALMS, and it was used to test and validate the created prototype. The alert business process starts with an 'alert generation' event which originates from the technology (physical layer) of the application. More specifically the alerts originate from the data collected from the sensors positioned in the edge layer. Afterwards, the gathered alerts from the technology layer are fed into the ALMS Maintenance Management application component. The alerts are collected and stored into a database for further processing and analysing. After being processed, predictive algorithms are applied to support the decision management process. The next step is to propose and execute decisions based on the analysis and schedule the maintenance. The alerts, decisions and scheduled maintenance are shown via a dashboard report.

2) Prototype Architecture: Figure 10 displays the architecture of the developed prototype. The prototype was designed to assist the efficient alert (failure notifications) generation process which is initiated from the cloud, fog, and edge layer and then used to optimize the maintenance scheduling actions of the ALMS system.

3) Prototype Implementation: This part of the created prototype is about usage of one application component specified in the ALMS, more specifically it refers to the ALMS Maintenance Management component. This prototype is not developed for the purpose of being implemented in a production environment, but only to represent the process of efficient alert generation (due to adding of the cloud, fog, and edge computing paradigm) to optimize the maintenance service for ALMS. The designed user interface only provides interactivity and small number of essential functionalities that refers to receiving notifications from the ALMS maintenance management application component.

The development platform used for our prototype is WebFlow [24]. It is a platform for building custom prototypes, blogs, portfolios, e-commerce stores, and many more with a flexible CMS. Additionally, it provides experience of the power of HTML, CSS, and JavaScript in a visual canvas. As declared in the enterprise architecture, one of the core components is the ALMS maintenance management application component, which is aggregated with the Maintenance management and predictive maintenance application collaboration entity.

The prototype starts with a login window, which leads to another page where a user can choose a specific role: technician, or an airfield ground controller. Then, the user inserts the login details, such as username and password. Afterwards, the user can access their own dashboard report.

Figure 11 shows the technician's dashboard view. The technician can have access to the required tasks, alerts, and

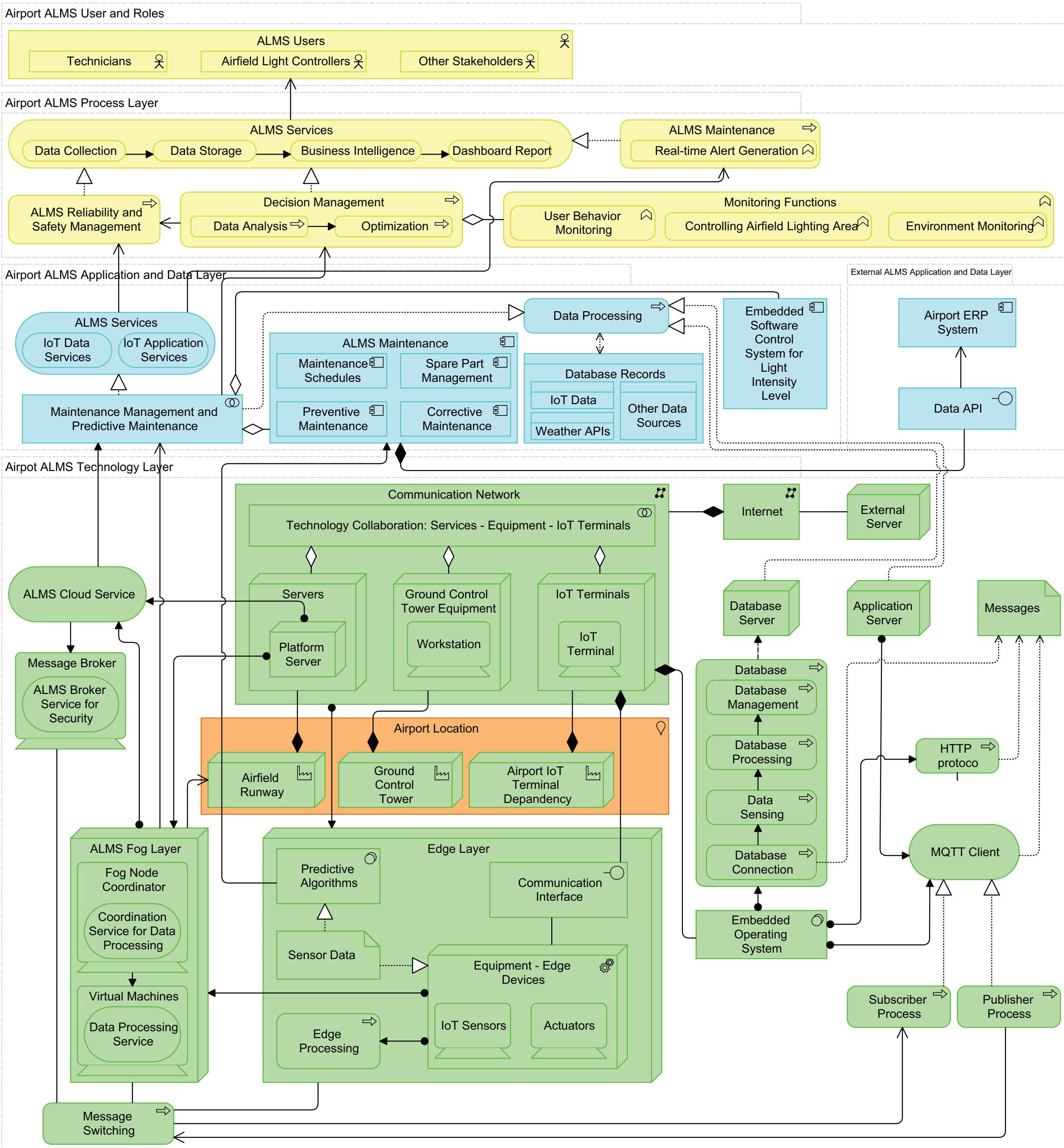

Fig. 8. Enterprise Architecture - ALMS Based on IoT

assets. Beneath the provided information, are listed the assets which require maintenance and most recent live alerts. The alerts refer to measured high levels of temperature and pressure by the sensors positioned on the airfield runway. The moment a user clicks on the *alerts* option, a new dashboard containing more details is accessed.

Figure 12 gives more details about the received alert that indicates a failure of a sensor node. The details are date/time of data reception; amount of data processed in the fog/edge layer; exact temperature and pressure measured for the specific sensor node; expected time of failure (date and time); and scheduled date for maintenance.

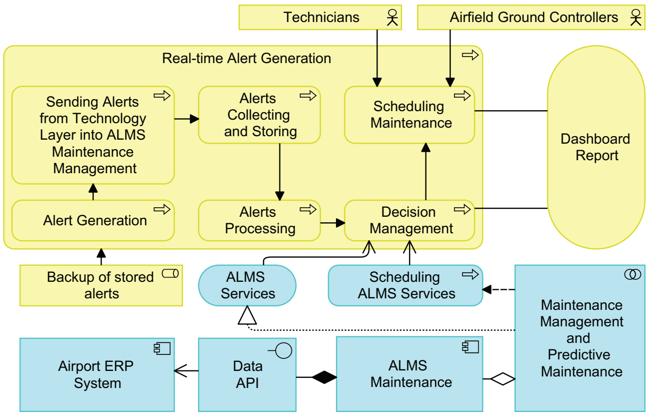

Fig. 9. Business Process Alert Generation for the Maintenance Process

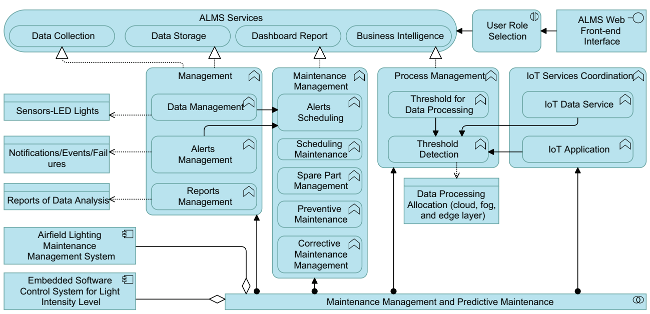

Fig. 10. Architecture of the Prototype

The technician needs just to approve the details of the provided alert and add the required maintenance task in the planning schedule.

B. Expert Evaluation

For evaluation of our architecture and prototype implementation, we asked several experts to evaluate the architecture. One half of the expert group joined a live presentation about description of the ALMS EA and its demonstration study via an online conference call, which was organized and given by the first author of this research article. The experts analysed and discussed the EA model, and then completed the provided survey. The other half of the expert group (enterprise architects from Dutch companies) considered a recording of the given presentation and afterwards provided answers to the delivered survey. The results of the conducted survey regarding five aspects of the Unified Theory of Acceptance and Use of Technology (UTAUT) model and additional two groups of questions will be discussed in details in this section. Descriptive statistics (mean, median, mode and standard deviation) of the survey are presented in Table I to describe the main aspects of the data and provide a summary of the findings of the survey. The goal of the standard deviation is to measure the dispersion of values around the central tendency.

The questions of the delivered survey were divided into seven groups and for the answers we used a 1 to 5 Likert scale, where 1 indicated *Weak* opinion and 5 indicated *Strong*

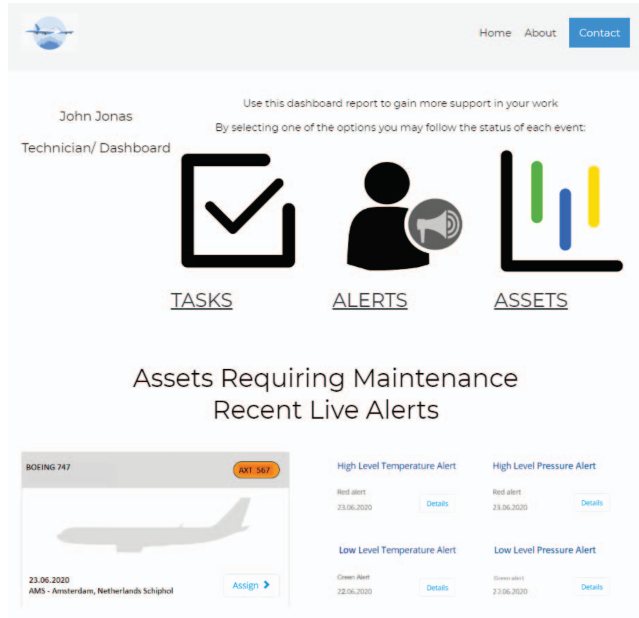

Fig. 11. Dashboard Report for a Technician Role

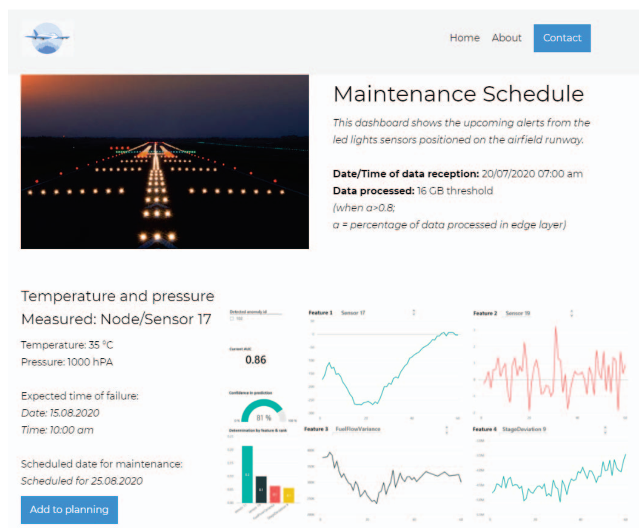

Fig. 12. Notification Alerts Dashboard to Support Maintenance

opinion. The seven groups of questions are the following: General (experience) questions [Q1-Q2], demonstration questions [Q3-Q5], performance expectancy [Q6-Q8], effort expectancy [Q9-Q11], attitude towards using technology [Q12-Q14], facilitating conditions [Q15-Q16] and anxiety [Q17-Q19]. The complete list of questions is given in Table I.

Based on the obtained results, we will elaborate the scores per question group, which are also presented in Figure 13. These scores represent the experts' opinion. The aim of presenting these results is just to deliver insights into the respondents' responses, but not obtain a generalizing opinion. The values to all questions, which are ranging between one and

TABLE I
EXPERT EVALUATION RESULTS

Questions	Expert 1	2	3	4	5	6	7	Average	Median	Mode	Std
1. Level of experience with EA	3	4	4	3	4	4	4	3.71	4	4	0.49
2. Level of domain knowledge regarding airport solutions	2	3	5	1	2	3	2	2.57	2	2	1.27
3. The sensors on an airfield runway provide real-time information about the failure rate of the system, which is useful for supporting the predictive maintenance operations.	4	2	5	5	5	5	4	4.29	5	5	1.11
4. Adding the fog-edge paradigm in the EA may contribute to improvement of the application performance, resource efficiency, reducing response time, and energy consumption.	3	5	3	5	5	3	3	3.86	3	3	1.07
5. Adding fog, cloud and edge computing layers in the physical layer of the EA will enable the reliability and safety of the system.	4	3	4	1	3	4	3	3.14	3	4	1.07
6. I would find the system proposed with this EA useful for airfield management.	4	4	5	3	4	4	2	3.71	4	4	0.95
7. Using the system proposed with this enterprise architecture enables its users to accomplish tasks more quickly.	4	2	3	3	4	3	3	3.14	3	3	0.69
8. Using the system proposed with the EA increases productivity of its users.	4	3	3	3	4	4	3	3.43	3	3	0.53
9. My interaction with the proposed EA would be clear and understandable.	4	3	1	5	3	3	1	2.86	3	3	1.46
10. It would be easy for me to become skillful at using the system proposed with this EA.	4	3	3	1	3	2	3	2.71	3	3	0.95
11. I would find the EA for the system easy to use.	4	4	4	5	3	2	2	3.43	4	4	1.13
12. Using this EA is a good idea.	5	4	4	4	4	4	4	4.14	4	4	0.38
13. The EA makes work more interesting.	4	3	3	5	3	3	4	3.57	3	3	0.79
14. I like working with the developed EA.	4	4	3	3	3	4	3	3.43	3	3	0.53
15. I have the knowledge necessary to use the system suggested with the EA.	4	3	1	5	2	3	3	3.00	3	3	1.29
16. The system proposed with the EA is not compatible with other systems.	2	2	3	3	3	2	1	2.29	2	2	0.76
17*. I feel apprehensive about using the EA.	4	3	3	4	3	3	3	3.29	3	3	0.49
18*. I hesitate to use the system proposed by the EA for fear of making mistakes I cannot correct.	4	5	3	3	3	3	3	3.43	3	3	0.79
19*. The EA is somewhat intimidating to me.	4	5	5	5	2	4	5	4.29	5	5	1.11

*A reverse Likert scale was used, starting from 5 (disagree) to 1 (agree).

two indicate negative feedback, three means neutral and upper values indicate positive feedback. The mean indicates the overall trend, while the standard deviation shows the difference in the evaluation of the participants, and are the main focus for this analysis. The mean value for each question ranges from 2.29 to 4.29. The mean value for 15 of the questions is equal or above 3, where 12 of the values are between 3.00 and 3.86, and 3 of the values are between 4.14 and 4.29. The most positive feedback is recorded for Q3, Q12, and Q19 with a value 4, and the lowest value of 2.29 for Q16.

Taking in consideration the standard deviation, a value equal to zero indicates that there is a strong agreement between the respondents, while a higher value than 1 means there is a variation among the respondent's answers.

1) General (Experience) Questions: Based on the answers regarding Q1, the mean score regarding the experts' experience with EA is 3.71. When they were asked to answer the question regarding their level of domain knowledge regarding smart airport solutions, the mean score of their responses is 2.57. Moreover, the mean score of this construct is 3.14, which indicates somewhat a positive attitude, while the measured average standard deviation is 0.96 and it means there is not so much variation and disagreement among the respondents.

2) Demonstration Questions: These questions are created to evaluate the users' understanding level of the demonstration study, for which purpose the specific EA was created. Q3 refers to whether the sensors on an airfield runway provide real-time information about the failure rate of the system, and that is useful for supporting the predictive maintenance operations. The positive score of this question can be supported with one of the expert's motivation that indicated the following: *"Collection of real-time data is useful for analysis, such that it supports the more accurate predictive maintenance."* Q4 was about whether adding the Fog-Edge paradigm in the enterprise architecture contributes to improvement of the application

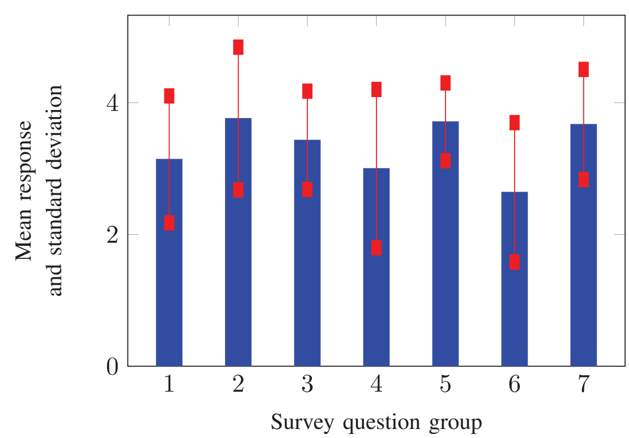

Fig. 13. Expert Evaluation per Question Group Depicted in a Boxplot with Standard Deviations

performance, resource efficiency, reducing response time and energy consumption. The average of the respondents scored 3.86, which indicates a positive evaluation. One of the most supportive motivations is: *"Fog edge option in this case allows certain level of preprocessing of data which off load central application."*

To conclude, the result implies that the experts have high level of understanding of the demonstration study (mean value 3.76, which is the highest obtained average score) and its concepts. The average standard deviation is 1.08 which also means that there is a certain variation in the answers from the respondents.

3) Performance Expectancy: Based on the answers regarding performance expectancy, it can be seen that most of the experts considered the created EA as useful and helpful. The mean value of the complete question group is 3.43 and it indicates a positive attitude, while the standard deviation shows the value of 0.75 and represents certain level of agreement between the experts. Some of the most supportive motivations that contributed for the positive score are: *"Nice innovation", and "The given infrastructure enables the users to have a better monitoring / controlling facilitation."*

4) Effort Expectancy: The questions are created to evaluate the easiness of use of the proposed EA. As shown in the survey results, all of the experts gave different scores regarding how clear and understandable would be the interaction of the system proposed with this EA. The mean score for Q9 is 2.86. The mean score for Q10 is 2.71. Positive feedback is shown for Q11 and that is regarding finding the enterprise architecture for the system easy to use. Some of the respondents stated the following: *"The model was of proper quality", "The provided Archimate simplified the interaction between the system components", and "The architecture provides a clear and comprehensive overview of the system that I can, given my background and knowledge, can understand quite well".*

The overall mean score for this question group is 3.00 which is somewhat positive. The average standard deviation value is 1.20, which indicated variation in the given responses.

5) Attitude Towards Using Technology: In this subsection of the evaluation, the attitude towards using technology was assessed. All of the experts gave high scores for Q12 and agreed that using this EA is a good idea. One expert stated that using the EA was a good idea since it provided simplified depiction of components and their interaction within the system. Another respondent supported the score with the following motivation *"This enterprise architecture contributes to understanding the system, more specifically its critical components and interfaces, behind the airfield lightning system and illustrates how predictive maintenance can support its functioning and performance."* Regarding Q13 and whether the enterprise architecture makes the work more interesting, the responses quite differ. Moreover, the statement in Q14 is quite subjective and therefore some participants can reasonably have different opinions regarding what really makes their work interesting.

The mean score of this question group is 3.71, which is quite a positive feedback, while the average standard deviation is 0.59 and it means that there is an agreement between the experts.

6) Facilitating Conditions: The scores provided to Q15 and whether the experts have the knowledge necessary to use the system suggested with the EA are varying. Somewhat negative feedback is obtained from Q16, regarding whether the system proposed with the enterprise architecture is not compatible with other systems. One of the motivations for the negative score is: *"Determining compatibility and interoperability with other systems requires a more detailed understanding of the systems and their interfaces."* The overall mean score is somewhat negative 2.64. The average standard deviation is 1.06, which indicates a certain level of disagreement between the opinions.

7) Anxiety: Questions from Q17 to Q19 belong to this question group and follow the reverse Likert scale, starting from 5 (Disagree) and 1 (Agree). In average it seems that there is a neutral towards positive opinion regarding this statement. Positive feedback was shown when participants were asked whether the enterprise architecture is somewhat intimidating to them. In overall this question group has been quite helpful to show whether the EA causes certain level of anxiety. The overall mean score is 3.67, which is quite positive. The average standard deviation is 0.84.

VII. Contributions

Prior research has shown that architectures are not completely exploiting the IoT in smart airport solutions. Therefore, the main contribution of this study is the proposed ALMS EA, which is based on the Cloud-Fog-Edge computing paradigm. The architecture portrays how predictive and preventive maintenance can be achieved, which is vital for energy management, sustainability, and deduction of communication costs. One important components of the architecture is to enable the management of event detection and failures in real-time. For example, the EA can be used to identify the failures of sensor nodes within airfield led-lights. A validation of the EA was completed by developing a prototype, which supports optimization of maintenance processes. The EA was evaluated through an evaluation survey delivered to several experts, and its results have shown positive evaluations for five question groups and indicated that improvement could be done for "Effort expectancy" and "Facilitating conditions". With this study, we managed to develop an enterprise architecture which can be used as a concept and a guideline for reliability and safety management systems for IoT-based smart airport solutions that embrace the Cloud-Fog-Edge computing paradigm.

VIII. Conclusion and Future Work

The aviation industry is lately regarded as one of the main factors for global warming and pollution. The decrease of fuel consumption costs, energy management, and resource management have become important for critical system infrastructures such as smart airfield lighting systems. With the architecture proposed in this study we believe that sustainability can be achieved by implementing a smart ALMS based on Cloud-Fog-Edge paradigm. The developed ArchiMate model for ALSM can support researchers and practitioners focusing on exploring approaches and methods to improve sustainability in smart airport solutions. Besides that, we only presented an EA following a demonstration, while it is important to validate the EA more rigorously in future. For example, one may use more advanced data analytics methods (e.g., simulations) and determine the EA's effectiveness more realistically. Thus, further work is needed to validate the usefulness of the EA for realistic and large-scale applications. Another interesting direction is to expand the prototype towards a complete Cloud-Fog-Edge implementation. The current prototype mainly focuses on the maintenance processes (business and application layer) and the link between the application and technology layer, but not showing the link between and within the cloud, fog, or edge components. Further empirical research (e.g., more expert assessments) is also needed to quantitatively evaluate the proposed approach. Lastly, the generalizability of the used validation approach and results can be expanded in future work. We recommend further research of the proposed (Cloud-Fog-Edge) solution, which can be applied in development of a reference architecture and validated in other application domains.

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